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Research Article

An evidence-based protocol for developing lists for tree planting

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Abstract

Tree-planting is increasingly being promoted for urban greening, carbon sequestration, and to enhance biodiversity. However, poorly planned and executed tree-planting schemes can inadvertently contribute to biological invasions with detrimental effects on local ecosystems, economies, and human well-being. Therefore, sustainable, rigorous, repeatable, and transparent species selection strategies are needed.

We developed a strategic decision protocol for identifying tree taxa suitable for planting schemes, using a multi-criterion approach that integrates national lists of regulated invasive plant species, global evidence of invasiveness, and susceptibility to key pests. Using the Polyphagous Shot Hole Borer (PSHB) invasion in the City of Cape Town, South Africa as a case study, we illustrate the protocol's application and potential for informing planting decisions.

444 tree taxa currently planted in Cape Town were assessed. Of these, 85 are regulated nationally as invasive species (and are prohibited from use), while 49 met all suitability criteria and were identified as candidates for a planting list (i.e., a safe list).

This protocol provides evidence-based guidance for tree-planting to mitigate the risk of tree invasions and to reduce the spread and impact of associated pests and pathogens. This protocol is replicable and adaptable for use in other regions and can support environmental planners and managers in making informed decisions to safeguard ecosystems and optimise ecosystem services (e.g., which trees to plant in restoration initiatives).

Key words: Alien species, biological invasions, ecosystem services, *Euwallacea fornicatus*, green infrastructure, *Neocosmospora euwallaceae*, pest management, treescapes, tree invasions, tree planting, urban greening

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Introduction

Tree-planting initiatives have gained widespread attention as a nature-based solution to global environmental challenges, including urban greening, carbon sequestration, biodiversity conservation, and climate-change mitigation (Roy et al. 2012; Bastin et al. 2019; Seddon et al. 2020). Across the world, governments, non-profit organisations, and communities are investing in large-scale tree-planting programs to restore ecosystems, improve air and water quality, and create green spaces that benefit both human health and wildlife (e.g., Bonn Challenge, the Great Green

Wall Initiative, Trillion Trees Campaign). Many of these tree-planting programs focus on rapid planting efforts to meet ambitious planting targets and often overlook major ecosystem impacts (Bond et al. 2019; Moyano et al. 2024) and other critical considerations such as appropriate species selection, site suitability, and the risks of future pest and pathogen invasions (Holl and Brancalion 2020).

As tree-planting initiatives gain momentum – often with considerable financial, political, and societal support – there is growing concern that poorly planned and executed efforts will inadvertently introduce new invasive non-native species or exacerbate existing invasions (Brundu and Richardson 2016; Blanchard et al. 2017). Such invasions, often facilitated by the planting of non-native tree species, can have devastating effects on ecosystems, economies, and human health (Richardson and Rejmánek 2011). The planting of native species, if done without regard to local pest dynamics, can also provide suitable hosts for invasive pests and pathogens (Paap et al. 2018). In some cases, the very trees intended to enhance biodiversity and provide ecosystem services can become vectors for pest proliferation, undermining the long-term goals of the initiative. These oversights can lead to reduced biodiversity, and compromised ecosystem services, creating the need for costly management interventions (Holl and Brancalion 2020; Bindewald et al. 2021).

South Africa has a long history of tree introductions, beginning with European colonisation in the mid-17th century (Poynton 1984; Richardson et al. 2003). The motivations for tree-planting have evolved over time – from meeting basic needs such as food, fuel, shade, and soil stabilisation to bolstering the forestry sector and improving agricultural systems (Richardson et al. 2003), and, more recently, enhancing urban environments (Potgieter et al. 2022). Despite the benefits of tree-planting, this practice has generated considerable controversy. For instance, many planted non-native tree species introduced for cultivation have become invasive, spreading beyond cultivation areas and causing major negative impacts (van Wilgen et al. 2022). A substantial invasion debt has accumulated, as many species have yet to fully realise their invasive potential or cause maximum impact (Rouget et al. 2016). Shifting environmental and socio-political conditions are influencing tree-planting policies and practices in South Africa. Rapid urbanisation is driving the development of new and expanding urban ecosystems, with efforts also underway to retrofit existing cities to enhance sustainability and liveability (van Staden and Stofberg 2021). Increasing tree cover has been deemed a key component of strategies to build resilience to global change.

The growing globalisation of trade, increased movement of people and goods, and changing climate patterns have contributed to a dramatic increase in the spread of pests and pathogens around the world (Hulme 2009; Raum et al. 2023). One of the most recent examples is the Polyphagous Shot Hole Borer (PSHB, *Euwallacea fornicatus*), an invasive ambrosia beetle, native to Southeast Asia, that has caused widespread damage around the world (Stouthamer et al. 2017; Van Rooyen et al. 2021). PSHB, along with its symbiotic fungus *Neocosmospora euwallaceae* L. Lombard & Crous, 2019 (previously *Fusarium euwallaceae*, Lombard et al. 2019), infests hundreds of taxonomically diverse tree species, such as *Acer negundo* L., *Quercus robur* L., and *Platanus* × *hispanica* Mill. ex Münchh., leading to significant tree mortality in both urban and natural environments (Freeman et al. 2016; Townsend et al. 2025). Invasive species like

PSHB thrive in urban landscapes, where a high density of susceptible host trees, coupled with human-mediated movement, accelerate the invasion process (Paap et al. 2020; Raum et al. 2023; Potgieter et al. 2024).

Although South Africa has faced extensive challenges from invasive species, particularly trees (van Wilgen et al. 2020, 2022), the country has until now avoided large-scale ecological disruptions from tree disease epidemics (Wilson et al. 2020) – though this is changing. The PSHB infestation in South Africa is part of a broader pattern where hundreds of tree species, many of which are critical for ecosystem services, are increasingly vulnerable to pests and pathogens (Paap et al. 2017; Raffa et al. 2023). This alarming trend underscores the importance of developing proactive measures to mitigate the risk of biological invasions in tree-planting efforts. While tree-planting remains a valuable strategy for conservation and climate change mitigation (Mader 2020; Moran et al. 2020), there is a pressing need to shift from *ad hoc* species selection to more strategic and evidence-based approaches that consider ecological risks.

Specifically, in the case of the PSHB infestation in South Africa, resulting urban tree mortality necessitates rigorous and transparent guidelines for replacement plantings that do not exacerbate plant or pest invasions in South Africa. Brundu et al. (2020) provide global guidelines for the sustainable use of non-native trees, outlining the precautions that should be taken when introducing and planting non-native trees. Their guidelines include eight key recommendations, including prioritising native or non-invasive non-native species, complying with regulations, assessing invasion risks under global change scenarios, implementing tailored silvicultural practices, and promoting early detection, stakeholder engagement, and international collaboration. These guidelines aim to support sustainable forestry, biodiversity conservation, and global environmental objectives. Further, Kumschick et al. (2024) outline considerations for developing and implementing a safe list for non-native taxa including criteria for risk assessments, stakeholder involvement, and regulatory mechanisms to ensure effective application.

Our goal is to operationalise these guidelines into a strategic protocol for tree selection that mitigates the invasion risk of both the planted trees and their associated pests and pathogens, using the PSHB invasion in South Africa as a case study.

Identifying tree taxa suitable for planting

To support evidence-based decision-making in tree-planting initiatives, we present a structured workflow that outlines the key steps required to identify tree taxa suitable for planting (Fig. 1). This workflow is designed to be adaptable to various regional contexts and ecological priorities, providing a replicable method for systematically screening candidate species lists using multiple risk-related criteria.

In our example, we apply this workflow to tree planting in the City of Cape Town Metropolitan Municipality, South Africa, a region facing significant challenges due to widespread tree invasions and the devastating impacts of PSHB on both natural and urban forests (de Wit et al. 2022). Cape Town was selected as a case study due to the availability of comprehensive data on planted trees and the urgency of mitigating pest and invasion risks. However, the steps presented here are broadly applicable and can be adapted to other cities or regions facing similar ecological pressures.

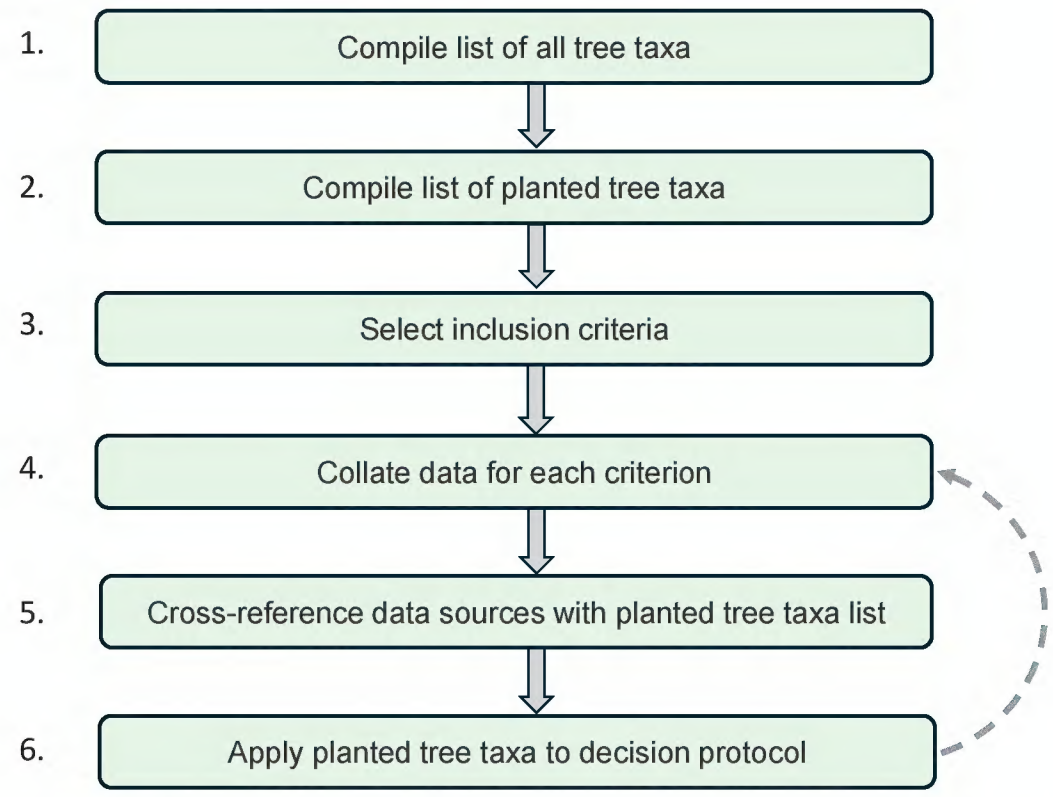

Figure 1. A generic workflow for identifying tree taxa suitable for planting. The process begins with compiling comprehensive lists of all tree taxa for the study region and those suitable for planting. Filtering and inclusion criteria are then defined, followed by data collation for each criterion. Relevant data sources are cross-referenced with the suitable taxa list, which is subsequently applied to a decision protocol to determine the final set of taxa recommended for planting. The workflow is iterative and adaptive (shown by the dashed arrow), with certain steps subject to ongoing refinement as new data and insights become available.

Step 1. Compile list of all tree taxa

The first step involves compiling a comprehensive, baseline list of all tree taxa already present in the study region, including both planted and non-planted trees. This broad list should capture the full diversity of tree species currently established in natural, semi-natural, urban, and cultivated settings. Data can be sourced from global and regional biodiversity databases such as the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/), GlobalTreeSearch (https://tools.bgci.org/global_tree_search.php), iNaturalist (https://www.inaturalist.org/), and national botanical databases. Gardening books, nursery catalogues (especially those specialising on trees), species lists from arboreta, and arborists and tree enthusiasts can also be consulted. Collaboration with local botanical gardens, forestry departments, and research institutions can ensure the list is exhaustive and regionally appropriate. To maintain taxonomic accuracy, names should be cross-checked against standardised taxonomic references such as the World Checklist of Vascular Plants (Govaerts et al. 2024). This process ensures consistency in species identification.

Step 2. Compile list of planted tree taxa

Once the full list of tree taxa present in the study region has been compiled, the next step involves narrowing this list to include only those taxa that are currently planted within the study region. This subset reflects taxa that are already in use in urban landscapes, parks, gardens, streetscapes, or other managed settings within the study region. The rationale is that these taxa have already been demonstrated to survive local conditions. This step is broadly applicable and can be implemented using municipal planting records, horticultural catalogues, or crowd-sourced

biodiversity platforms such as iNaturalist. In addition to taxa already planted in the study region, the list can be expanded to include species not yet planted locally but identified as suitable through established risk assessments, climate-adapted species guidelines, or provenance trials. These candidate taxa should be supported by robust evidence and aligned with local ecological and regulatory contexts.

For this study, we used the national planted tree inventory for South Africa, which comprises over 35,000 records of the 805 tree taxa currently planted across the country (hereinafter referred to as the "tree inventory"; Richardson and Potgieter 2024). Only tree taxa already present in South Africa were considered for planting to avoid promoting new introductions. Introducing new species carries inherent ecological risks, including unforeseen invasion potential, and requires rigorous screening before imports are approved [for details of the process in South Africa see Wilson and Kumschick (2024)]. The resulting list of regionally established tree taxa constitutes the candidate pool for further evaluation against invasion and pest risk criteria.

Step 3. Select inclusion criteria

A key component of the protocol involves establishing clear criteria to systematically assess the potential risks associated with planting particular tree taxa. This step ensures that species selection is not based on *ad hoc* or subjective preferences. The criteria define which attributes are relevant to determining whether a given tree taxon should be recommended for or excluded from planting initiatives. These criteria can be tailored to the specific goals, context, and management priorities of a given region.

In this study, these criteria include key risk factors associated with both tree invasiveness and susceptibility to PSHB. The first criterion focused on the regulatory status of tree taxa, specifically identifying those taxa listed as invasive under South Africa's National Environmental Management: Biodiversity Act 10 of 2004 Alien and Invasive Species Regulations [NEM:BA A&IS Regulations, these were most recently updated in 2020, for details see Wilson and Kumschick (2024)]. However, official lists might not capture emerging or localised invasions, especially in regions with infrequently updated invasive species lists. To address this, collaboration with local practitioners can help identify incipient invasions and ensure planting decisions reflect the most current on-the-ground knowledge.

The second criterion considered PSHB host status, distinguishing between *Neocosmospora*-colonised, competent, and kill-competent hosts (Townsend et al. 2025). *Neocosmospora*-colonised hosts are those in which fungal transmission from PSHB is possible, but which do not support beetle reproduction. Competent hosts are those in which the beetle successfully establishes a natal gallery and produces offspring. Kill-competent hosts included those tree taxa for which at least one individual has been documented as succumbing to the combined effects of the beetle and *N. euwallaceae* infestations. To implement these criteria, multiple data sources were consulted.

While the two primary criteria outlined here are central to our case study, the protocol allows for additional criteria to be used. For example, in other regions, filters based on climate suitability, fire susceptibility, or social and cultural values might be relevant. The selection and prioritisation of criteria should be adapted according to local ecological contexts, regulatory frameworks, and stakeholder needs, ensuring that the protocol remains flexible and applicable across diverse planting scenarios.

Step 4. Collate data for each criterion

With the criteria established, the next step involves collating taxa lists for each criterion. Multiple independent datasets should be used wherever possible to ensure a robust and transparent assessment. Appropriate data sources will vary depending on the focus of the assessment, the availability of region-specific information, and the geographic scope of the protocol's application.

We used 1) the NEM:BA A&IS Lists of 2020 (Wilson 2024) to determine the regulatory status and legal implications for each taxon, 2) the biogeographical status (native or non-native) using the categorisation of Richardson and Potgieter (2024), 3) the Global Naturalised Alien Flora (GloNAF, updated following van Kleunen et al. 2019) to determine whether each taxon is naturalised in and/or outside of South Africa, 4) the PSHB global host list (DPIRD 2024), which was compiled and validated using molecular records confirming PSHB identity from multiple sources, and 5) Lynch et al. (2025) to determine the host status of each tree taxon. We also identified taxa potentially susceptible to PSHB infestation by evaluating whether they belong to the same genus as confirmed PSHB hosts, given the increased likelihood of susceptibility among closely related species (Lynch et al. 2025); noting such taxa might have not yet been exposed, infections not formally recorded yet, or could become susceptible over time. To account for differing *Neocosmospora* susceptibilities within genera, taxa with unknown statuses were conservatively assigned the highest known risk level among their congeners. This precautionary approach aims to ensure that potential risks were not underestimated, i.e., it is a conservative assessment of host susceptibility.

Step 5. Cross-referencing data sources with planted taxa list

Once all relevant data have been collated for each criterion, the next step involves integrating these datasets with the curated list of planted tree taxa. This step is the core analytical phase of the protocol, as it integrates the multiple risk factors assessed in the previous step. By systematically cross-referencing each tree taxon against the selected data sources, comprehensive, evidence-based classification can be developed that identifies taxa suitable for planting, those that should be excluded, and those requiring further monitoring.

We cross-referenced our curated list of planted tree taxa with multiple key data sources (described above). This process involved extracting and assigning attributes to each taxon, including its listing in the NEM:BA A&IS Regulations, invasion status, and PSHB host status. This approach ensured that each taxon was evaluated using multiple, independent criteria, allowing for a robust and evidence-based classification of tree taxa in relation to both invasion potential and susceptibility to PSHB.

Step 6. Apply planted tree taxa to decision protocol

We present a structured, evidence-based decision protocol to support the identification of tree taxa suitable for planting (Fig. 2). Designed to guide planners, land managers, and policymakers, the protocol follows a sequence of filtering and assessment steps that incorporate both general ecological risks, such as naturalisation potential, and context-specific threats, including pest or pathogen susceptibility.

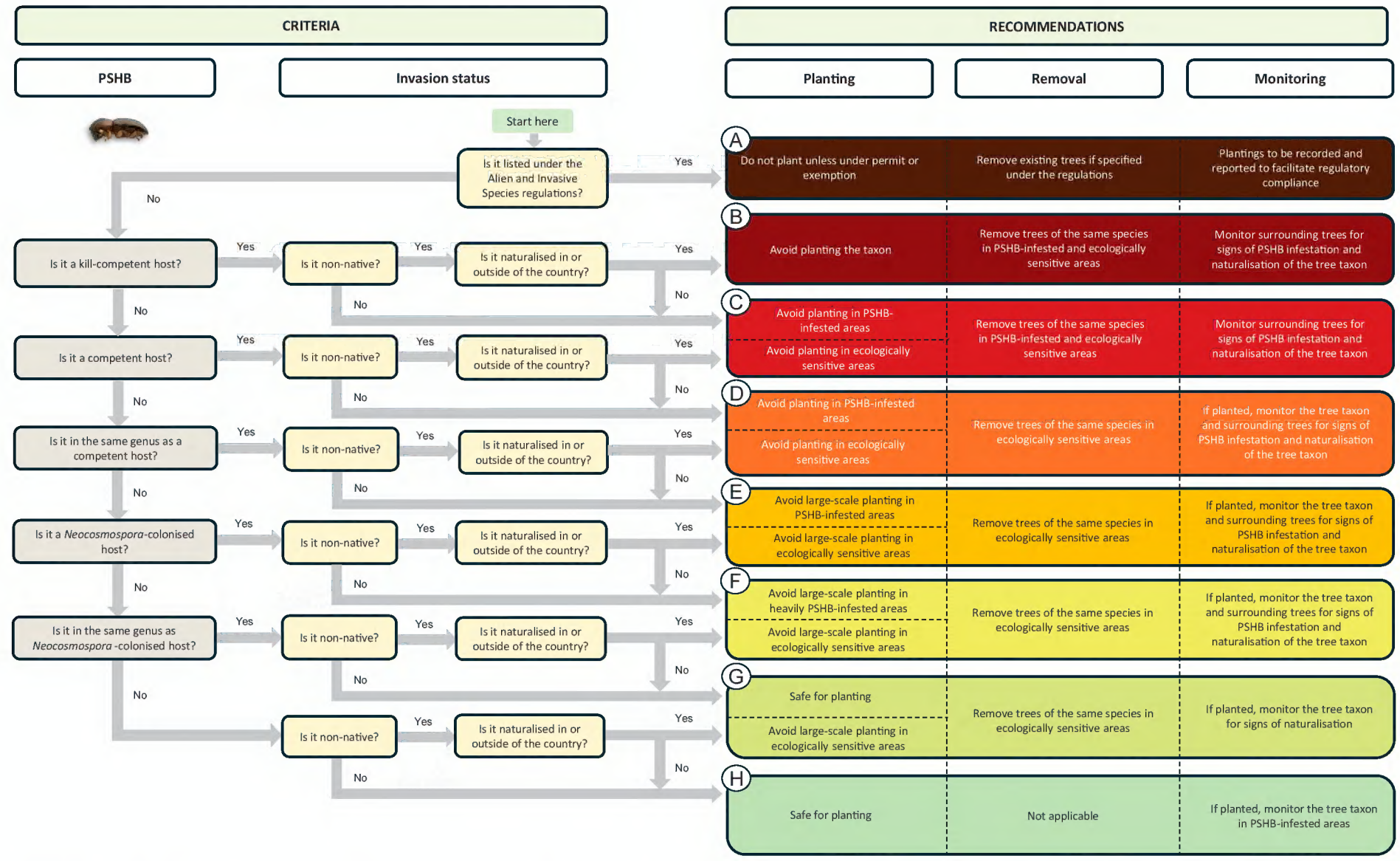
CRITERIA
RECOMMENDATIONS
PSHB
Invasion status
Planting
Removal
Monitoring
Start here
Is it listed under the Alien and Invasive Species regulations?
Yes
No
Is it a kill-competent host?
Is it a competent host?
Is it in the same genus as a competent host?
Is it a Neocosmospora-colonised host?
Is it in the same genus as Neocosmospora -colonised host?
Is it non-native?
Is it naturalised in or outside of the country?
A
Do not plant unless under permit or exemption
Remove existing trees if specified under the regulations
Plantings to be recorded and reported to facilitate regulatory compliance
B
Avoid planting the taxon
Remove trees of the same species in PSHB-infested and ecologically sensitive areas
Monitor surrounding trees for signs of PSHB infestation and naturalisation of the tree taxon
C
Avoid planting in PSHB-infested areas
Avoid planting in ecologically sensitive areas
Remove trees of the same species in PSHB-infested and ecologically sensitive areas
Monitor surrounding trees for signs of PSHB infestation and naturalisation of the tree taxon
D
Avoid planting in PSHB-infested areas
Avoid planting in ecologically sensitive areas
Remove trees of the same species in ecologically sensitive areas
If planted, monitor the tree taxon and surrounding trees for signs of PSHB infestation and naturalisation of the tree taxon
E
Avoid large-scale planting in PSHB-infested areas
Avoid large-scale planting in ecologically sensitive areas
Remove trees of the same species in ecologically sensitive areas
If planted, monitor the tree taxon and surrounding trees for signs of PSHB infestation and naturalisation of the tree taxon
F
Avoid large-scale planting in heavily PSHB-infested areas
Avoid large-scale planting in ecologically sensitive areas
Remove trees of the same species in ecologically sensitive areas
If planted, monitor the tree taxon and surrounding trees for signs of PSHB infestation and naturalisation of the tree taxon
G
Safe for planting
Avoid large-scale planting in ecologically sensitive areas
Remove trees of the same species in ecologically sensitive areas
If planted, monitor the tree taxon for signs of naturalisation
H
Safe for planting
Not applicable
If planted, monitor the tree taxon in PSHB-infested areas

Figure 2. Decision protocol for tree selection to mitigate the risk of Polyphagous Shot Hole Borer (PSHB, *Euwallacea fornicatus*) infestation and tree invasions. The protocol consists of eight recommendations categorised into three types: tree-planting, tree removal, and tree monitoring. These recommendations are further grouped into scenarios, represented by a colour gradient from dark brown to green. Scenario B is when planting the tree taxon can result in a high likelihood of both PSHB infestation and invasion of the tree taxon itself, necessitating the exclusion of certain tree taxa from planting initiatives. Progressively lighter shades represent decreasing likelihood of PSHB infestation and/or tree invasion, with green denoting tree taxa posing a low likelihood of both PSHB infestation and tree invasion and which are thus suitable for planting. Should there be any uncertainty regarding decisions, the global data sources highlighted in the Methods section (or any region-specific data sources relevant to the local context) should be consulted.

The decision protocol integrates the outputs of Steps 3–5 into a transparent, repeatable framework for determining which tree taxa are suitable for planting or should be excluded. It consists of eight targeted recommendations (variously addressing tree planting, removal, and monitoring). In cases of uncertainty, the protocol encourages consultation of global or region-specific data sources to refine recommendations.

The protocol is intended for a wide range of stakeholders, including government agencies, non-governmental organisations, environmental consultants, landscape architects, and restoration practitioners. While particularly relevant to urban and municipal planning, it is equally applicable to broader forest and land-use contexts. Its flexible, multi-criterion structure enables users to identify low-risk tree taxa tailored to local ecological conditions and regulatory frameworks, thereby reducing the likelihood of biological invasions and pest outbreaks. Although some familiarity with tree ecology and access to relevant data are beneficial, the protocol is designed to be transparent, adaptable, and accessible to users with varying levels of expertise. Where needed, implementation can be supported through collaboration with experts or local authorities.

We applied this protocol to the City of Cape Town Metropolitan Municipality, and categorised tree taxa from high to low likelihood of PSHB infestation and invasion of the tree taxon itself. Targeted recommendations associated with each category were also provided. The city has the most comprehensive planted tree data coverage of any municipality in South Africa (Richardson and Potgieter 2024) and has also recently experienced PSHB invasions (first detected in 2019) with over 10,000 trees infested and ~4000 already removed from public land due to PSHB infestation (City of Cape Town Invasive Species Unit, pers. comm., 14 March 2025; Fig. 3a). The city has a relatively low tree canopy cover at just six percent (City of Cape Town 2021), and this is likely to decrease further due to urban expansion, tree removals for infrastructure development, the impacts of climate change, and pest-pathogen infestations. By aligning with global frameworks such as the United Nations Sustainable Development Goals (United Nations 2015), and initiatives like the New Urban Agenda (United Nations 2017), and the Global Covenant of Mayors for Climate and Energy (GCoM 2022), Cape Town has committed to developing policies that aim to augment its green infrastructure to meet these international targets while ensuring a healthier, more liveable future for its residents.

Applying the protocol at the municipal level allows for context-specific decisions that align with environmental conditions, socio-economic priorities, and regulatory requirements. This scale also supports integration with urban greening, biodiversity conservation, and climate resilience strategies, and fosters collaboration with local stakeholders. The protocol is broadly transferable and can be adapted to address different threats (e.g., drought mortality, flammability) and applied across spatial scales, from municipalities to provinces or countries, depending on available data and regional priorities.

The workflow produces an evidence-based list of tree taxa safe for planting, providing a scientifically informed foundation for species selection in tree-planting initiatives. In our case study, the tree taxa on this list are 1) not currently listed as invasive under national legislation, 2) not known to be naturalised in South Africa or elsewhere, and 3) not known to be susceptible to PSHB. These taxa can therefore currently be recommended as suitable for planting in the city. Depending on the application, lists can be tailored to specific land-use contexts (e.g., street trees vs. riparian buffers) or demographic needs (e.g. allergen-free trees for schools). The list can also support nursery industry planning and public procurement by highlighting demand for low-risk species. The lists should be reviewed periodically as new data emerge.

The availability of taxa on this list in nurseries or online plant retailers in South Africa was also assessed. To determine this, we searched a representative selection of nursery catalogues, including both printed catalogues from major South African wholesale and retail nurseries and publicly available online platforms. Online plant retail stores were identified through targeted keyword searches (e.g., "buy [species name] tree South Africa", "tree nursery South Africa", "ornamental tree sales South Africa"). Each taxon from the final filtered list was cross-checked against these sources to record its availability in one or more life stages (seeds, seedlings, saplings, or mature trees). A taxon was considered accessible if it was available for sale at any life stage (seeds, seedlings, saplings, or mature trees) through at least one nursery or online plant retailer. This process provided an indication of each taxon's accessibility within the horticultural trade, which is relevant for practical implementation of planting recommendations.

Figure 3. Photo panel including. **a.** Polyphagous Shot Hole Borer (PSHB, *Euwallacea fornicatus*; photo credit: A de Villiers); **b.** A popular ornamental tree *Metrosideros excelsa* Sol. ex Gaertn. (New Zealand Christmas tree; photo credit: DM Richardson) listed under South Africa's National Environmental Management: Biodiversity Act 10 of 2004 Alien and Invasive Species Regulations; **c.** Signs of PSHB infestation of *Acer negundo* L. (Box elder; photo credit: LJ Potgieter), a kill-competent host, and **d.** *Dais cotinifolia* L. (Pom Pom tree; photo credit: DM Richardson) currently deemed safe for planting across the City of Cape Town Metropolitan Municipality.

Case study: City of Cape Town

Decision protocol

Tree taxa listed under the NEM:BA A&IS Regulations must not be planted unless a permit or exemption has been granted by the relevant environmental authority (scenario A, Fig. 3b). Unauthorised planting can result in legal consequences and contribute to socio-ecological and economic impacts and conflicts.

If a permit or exemption is granted, plantings should be recorded and reported to facilitate regulatory compliance, carefully monitored to prevent unintended spread, and measures taken to reduce the likelihood of spread.

Kill-competent host trees that are naturalised in or outside of the country should not be considered for planting (scenario B, Fig. 3c). Their susceptibility to PSHB means they can serve as breeding reservoirs, amplifying PSHB populations (Townsend et al. 2025). As naturalised taxa, these trees can spread in and around the planting site leading to ecological and socio-economic impacts, including loss of biodiversity, and costly control efforts (Richardson and Rejmánek 2011). If the planting site is in or close to a PSHB-infested and/or ecologically sensitive area, such as a protected area, riparian zone or wetland, removing kill-competent, naturalised host trees is recommended, and all trees in and around the planting site should be monitored for early signs of PSHB infestation and naturalisation of the tree taxon. This approach can reduce beetle numbers and the likelihood of the spread of invasive trees. Planting of native kill-competent host trees, especially in PSHB-infested areas, and competent host trees that are naturalised in or outside of the country is also not recommended and alternative tree taxa should be considered (scenario C). The above-mentioned tree removal and monitoring recommendations also apply.

Planting of native competent host trees, and taxa in the same genus as competent host trees that are naturalised in or outside of the country, especially in PSHB-infested areas, is not recommended and alternative tree taxa should be considered (scenario D). Taxa in the same genus as competent hosts are more likely to be susceptible to PSHB than more distantly related taxa, either due to shared physiological traits or the possibility of the beetle adapting to utilise the tree over time (Lynch et al. 2025). If planting of such trees is carried out, these, and all trees in and around the planting site, should be monitored for signs of naturalisation and PSHB infestation.

Large-scale planting (many trees planted over a large area) of native taxa in the same genus as competent host trees, especially in PSHB-infested areas, and *Neocosmospora*-colonised host trees that are naturalised in or outside of the country is also not recommended and alternative tree taxa should be considered (scenario E). Where a tree taxon is a native *Neocosmospora*-colonised host tree, large-scale planting should still be avoided in heavily infested areas, but it can be planted more broadly, including in areas with some PSHB presence, provided the trees are regularly monitored for signs of PSHB infestation (scenario F). Large-scale planting of taxa in the same genus as *Neocosmospora*-colonised host trees that are also naturalised in or outside of the country should be avoided in ecologically sensitive areas (scenario F).

Native taxa in the same genus as *Neocosmospora*-colonised host trees can be considered safe for planting, although the planted trees should still be monitored for signs of PSHB infestation in known infestation zones (scenario G). Large-scale planting of taxa that are not known hosts or closely related to any hosts, but that are naturalised in or outside of the country should be avoided (scenario G). Taxa that are not known hosts with no evidence of naturalisation can be considered safe for planting, but should still be monitored for signs of PSHB infestation if planted in known infestation zones (scenario H, Fig. 3d).

In cases where the planting site is in or close to an ecologically sensitive area, removing trees that are naturalised in or outside of the country is recommended where feasible, and the planting site should be monitored for signs of naturalisation of the tree taxon. In cases where PSHB infestations persist, maintaining detailed records of affected tree locations, host species, and management interventions

will provide valuable data to refine control strategies and improve long-term invasion management efforts.

For areas outside of PSHB-infested or ecologically sensitive zones, tree-planting should prioritise taxa that are not known PSHB hosts and have no evidence of naturalisation (scenario H). Additionally, taxa in the same genus as *Neocosmospora*-colonised hosts can be considered safe for planting, provided regular monitoring is conducted in regions where PSHB infestations may emerge (scenario G). While large-scale planting of taxa that are not known PSHB hosts but are naturalised in or outside of the country should be avoided due to their potential invasion risk (scenario G), selective planting of such species may be permissible in controlled urban settings where their spread can be managed. However, these trees should be monitored to detect any signs of naturalisation or pest susceptibility.

Tree suitability outcomes

We applied the decision protocol to the City of Cape Town Metropolitan Municipality to produce the first systematic risk-based assessment of trees suitable for planting. Records of planted trees within the City's municipal boundary were extracted from our planted tree taxa list [Richardson and Potgieter (2024)'s inventory] to create a dataset of 444 planted tree taxa for the city. The protocol categorised these 444 planted tree taxa based on their invasion status and PSHB host status (see Potgieter 2025 for the full dataset).

Of the 444 assessed taxa, 85 taxa (19%) are currently regulated under NEM:BA A&IS and must not be planted. Nine taxa were identified as kill-competent hosts, five of which are non-native and naturalised. Competent hosts included 57 taxa which are predominantly non-native and naturalised. Beyond confirmed hosts, 81 taxa share a genus with a competent host, and 68 taxa are *Neocosmospora*-colonised hosts. While 115 taxa are not known to be PSHB hosts (or closely related to known hosts) in the city, 66 of these were non-native and naturalised and are not recommended for planting. Only 49 taxa (12 non-native species that have not naturalised and 37 native species) were identified as suitable for planting (scenario H, Table 1). Of these taxa, 32 (of which 29 are native) are available for purchase through South African nurseries or online plant vendors, indicating a relatively high level of commercial accessibility (Table 2).

These findings emphasise the limited proportion of low-risk options available for urban planting in Cape Town and demonstrate the value of applying structured, evidence-based protocols to support safe species selection. They also illustrate the urgent need for targeted replacement strategies and nursery propagation efforts focused on expanding the availability of low-risk, native, or non-naturalised tree species to promote resilient and sustainable urban treescapes.

Key considerations for safe tree-planting

Our tree selection protocol incorporates invasive species regulations, global invasion records, and pest-host interactions, and ensures that tree-planting schemes do not inadvertently facilitate biological invasions or exacerbate pest outbreaks. This protocol helps operationalise global guidelines into region-specific guidance by providing decision-makers with an evidence-based tool to minimise ecological and economic risks while promoting sustainable and resilient tree-planting practices in the face of global change.

Table 1. Number of planted tree taxa per recommendation category when applied to the City of Cape Town Metropolitan Municipality (total planted tree taxa = 444). Data from Richardson and Potgieter (2024). For details of the recommendations see Figure 2. Fifty tree taxa are deemed safe for planting in the city (Table 2). Regulated as invasive is based on the inclusion of taxa in the National Environmental Management: Biodiversity Act (10 of 2004) Alien & Invasive Species Lists of 2020 (Wilson 2024). The taxonomic nomenclature follows the World Checklist of Vascular Plants (Govaerts et al. 2024).

Criteria		Number of planted tree taxa	Scenario	Example tree taxon
PSHB susceptibility	**Invasion status**			
	Regulated as invasive	85	A	*Melaleuca viminalis* (Sol. ex Gaertn.) Byrnes
Kill-competent host	Non-native, naturalised	5	B	*Acer negundo* L.
	Non-native	1	C	*Platanus* × *hispanica* Mill. ex Münchh.
	Native	3	C	*Erythrina lysistemon* Hutch.
Competent host	Non-native, naturalised	42	C	*Populus simonii* Carrière
	Non-native	3	D	*Platanus* × *hispanica* Münchh.
	Native	12	D	*Erythrina afra* Thunb.
Same genus as a competent host	Non-native, naturalised	41	D	*Syzygium australe* (J.C.Wendl. ex Link) B.Hyland
	Non-native	20	E	*Quercus leucotrichophora* A.Camus
	Native	20	E	*Bauhinia tomentosa* L.
Neocosmospora-colonised host	Non-native, naturalised	43	E	*Celtis sinensis* Pers.
	Non-native	3	F	*Olea europaea* subsp. *europaea*
	Native	22	F	*Ekebergia capensis* Sparrm.
Same genus as a *Neocosmospora*-colonised host	Non-native, naturalised	13	F	*Washingtonia robusta* H.Wendl.
	Non-native	5	G	*Pistacia lentiscus* L.
	Native	11	G	*Schotia afra* Thunb.
Not a known host	Non-native, naturalised	66	G	*Pinus pinea* L.
	Non-native	12	H	*Agathis australis* (D.Don) Lindl.
	Native	37	H	*Curtisia dentata* (Burm.f.) C.A.Sm.

When recommending a list of tree taxa suitable for planting, additional ecological and biogeographical factors must be carefully considered to ensure responsible species selection. Below, we discuss some of these key factors including: determinants of invasion (such as species traits, propagule pressure, and environmental conditions) that can contribute to the spread and establishment of non-native tree taxa; relevant regulations and risk analyses, outlining legal frameworks and scientific approaches used to assess and mitigate invasion risks; tree management practices such as community engagement, biodiversity-based planting, and inequities in tree distribution; and monitoring, emphasising long-term surveillance, early detection of invasive behaviour, and adaptive management strategies to ensure sustainable urban greening efforts.

Determinants of invasiveness

The likelihood of a species becoming invasive is shaped by how long it has been present in a region (residence time), the number of propagules introduced (propagule pressure), the configuration of plantings, and the ability of the species to establish under local climatic conditions (Wilson et al. 2007; Pyšek et al. 2009; Donaldson et al. 2014). When selecting tree species for planting, it is critical to evaluate invasion histories from regions with similar climates to the study region, as species that have naturalised or become invasive in these regions can exhibit similar trends locally (Kinlock et al. 2022). For example, Mediterranean-climate regions such as

Table 2. List of tree taxa suitable for planting in the City of Cape Town Metropolitan Municipality, South Africa. These taxa are: not listed under the Alien and Invasive Species Regulations; not known to be naturalised in or outside of South Africa; and are not known Polyphagous Shot Hole Borer hosts, i.e. are 'safe' sensu Kumschick et al. (2024). Their availability in nurseries or online plant retailers as seeds, seedlings, saplings, or mature trees, in South Africa is also indicated. The taxonomic nomenclature follows the World Checklist of Vascular Plants (Govaerts et al. 2024).

Scientific name	Common name	Family name	Native/Non-native	Available in nurseries
Agathis australis (D.Don) Lindl.	Kauri	Araucariaceae	Non-native	Unknown
Aloidendron barberae (Dyer) Klopper & Gideon F.Sm.	Tree Aloe	Asphodelaceae	Native	Yes
Aloidendron dichotomum (Masson) Klopper & Gideon F.Sm.	Quiver Tree	Asphodelaceae	Native	Yes
Aloidendron pillansii (L.Guthrie) Klopper & Gideon F.Sm.	Giant Quiver Tree	Asphodelaceae	Native	Unknown
Aloidendron ramosissimum (Pillans) Klopper & Gideon F.Sm.	Maiden's Quiver Tree	Asphodelaceae	Native	Unknown
Aloidendron tongaense (Van Jaarsv.) Klopper & Gideon F.Sm.	Tonga Tree Aloe	Asphodelaceae	Native	Yes
Anthocleista grandiflora Gilg	Forest Big-Leaf	Gentianaceae	Native	Yes
Antidesma venosum E.Mey. ex Tul.	Tassel-Berry	Phyllanthaceae	Native	Yes
Apodytes dimidiata E.Mey. ex Arn.	White Pear	Metteniusaceae	Native	Yes
Araucaria rulei F.Muell.	Rule Araucaria	Araucariaceae	Non-native	Unknown
Bolusanthus speciosus (Bolus) Harms	Tree Wisteria	Fabaceae	Native	Yes
Boscia albitrunca (Burch.) Gilg & Gilg-Ben.	Shepherd's Tree	Capparaceae	Native	Yes
Brabejum stellatifolium L.	Wild Almond	Proteaceae	Native	Yes
Breonadia salicina (Vahl) Hepper & J.R.I.Wood	Matumi	Rubiaceae	Native	Yes
Bridelia micrantha (Hochst.) Baill.	Mitzeeri	Phyllanthaceae	Native	Yes
Buckinghamia celsissima F.Muell.	Ivory Curl	Proteaceae	Non-native	Unknown
Burchellia bubalina (L.f.) Sims	Wild Pomegranate	Rubiaceae	Native	Yes
Canthium inerme (L.f.) Kuntze	Turkey-Berry	Rubiaceae	Native	Yes
Caryota no Becc.	Giant Fishtail Palm	Arecaceae	Non-native	Unknown
Chionanthus foveolatus (E.Mey.) Stearn	Pock Ironwood	Oleaceae	Native	Yes
Curtisia dentata (Burm.f.) C.A.Sm.	Assegai	Curtisiaceae	Native	Yes
Dacrydium cupressinum Sol. ex G.Forst.	Rimu	Podocarpaceae	Non-native	Unknown
Dais cotinifolia L.	Pom Pom Tree	Thymelaeaceae	Native	Yes
Dodonaea viscosa (L.) Jacq.	Sand Olive	Sapindaceae	Native	Yes
Elaeodendron croceum (Thunb.) DC.	Saffronwood	Celastraceae	Native	Yes
Euclea natalensis A.DC.	Natal Guarri	Ebenaceae	Native	Yes
Euclea racemosa L.	Sea Guarri	Ebenaceae	Native	Yes
Euclea undulata Thunb.	Common Guarri	Ebenaceae	Native	Unknown
Hesperocyparis forbesii (Jeps.) Bartel	Tecate Cypress	Cupressaceae	Non-native	Unknown
Heteropyxis natalensis Harv.	Lavender Tree	Myrtaceae	Native	Yes
Leucadendron argenteum (L.) R.Br.	Silver Tree	Proteaceae	Native	Yes
Murraya koenigii (L.) Spreng.	Curry Leaf Tree	Rutaceae	Non-native	Yes
Phyllocladus trichomanoides D.Don	Tanekaha	Podocarpaceae	Non-native	Unknown
Ptaeroxylon obliquum (Thunb.) Radlk.	Sneezewood	Rutaceae	Native	Yes
Raphia australis Oberm. & Strey	Kosi Palm	Arecaceae	Native	Yes
Rauvolfia afra (Sond.) K.Schum.	Quinine Tree	Apocynaceae	Native	Yes
Sabal mexicana Mart.	Mexican Palmetto	Arecaceae	Non-native	Unknown
Sideroxylon inerme L.	White Milkwood	Sapotaceae	Native	Yes
Tarchonanthus camphoratus L.	Camphor Bush	Asteraceae	Native	Yes
Tarchonanthus littoralis P.P.J.Herman & D.S.Court	Coast Camphor Bush	Asteraceae	Native	Unknown
Tarchonanthus trilobus DC.	Mountain Camphor Bush	Asteraceae	Native	Unknown
Tilia × *europaea* L.	Common Lime	Malvaceae	Non-native	Unknown
Volkameria glabra (E.Mey.) Mabb.	Smooth Volkameria	Lamiaceae	Non-native	Yes
Warburgia salutaris (G.Bertol.) Chiov.	Pepper-Bark Tree	Canellaceae	Native	Yes
Widdringtonia nodiflora (L.) Powrie	Mountain Cypress	Cupressaceae	Native	Yes
Widdringtonia schwarzii (Marloth) Mast.	Willowmore Cedar	Cupressaceae	Native	Unknown
Widdringtonia cedarbergensis J.A.Marsh.	Clanwilliam Cedar	Cupressaceae	Native	Unknown
Wollemia nobilis W.G.Jones, K.D.Hill & J.M.Allen	Wollemi Pine	Araucariaceae	Non-native	Unknown
× *Hesperotropsis leylandii* (A.B.Jacks. & Dallim.) Garland & G.S.Patterson	Leyland Cypress	Cupressaceae	Non-native	Yes

Australia and California, USA, provide useful comparisons for assessing potential invaders in the Cape Floristic Region of South Africa, while subtropical areas such as Florida offer insights into risks for parts of South Africa's east coast (Thuiller et al. 2005; Richardson and Thuiller 2007). The inclusion of climatic compatibility models in decision tools can further refine predictions of which taxa are likely to spread beyond intended planting zones (Petitpierre et al. 2012).

When selecting tree species for planting, it is critical to consider traits linked to increased invasiveness, as these characteristics can enhance a species' ability to establish, spread, and compete with native vegetation (van Kleunen et al. 2010). High seed production increases propagule pressure, ensuring that a species can rapidly colonise new areas, especially if seeds are viable for extended periods or germinate under a wide range of conditions (Lockwood et al. 2005). Long-distance dispersal mechanisms, such as wind-dispersed seeds (e.g., pines) or seeds carried by animals (e.g., fleshy fruits consumed by birds), enable species to escape from cultivation to invade natural ecosystems (Aronson et al. 2007). Clonal reproduction, where trees propagate vegetatively through root suckers or resprouting, allows for rapid spread even in the absence of seed-based reproduction, making control efforts particularly challenging (Klimešová and Martínková 2022). Taxa with strong resprouting ability after disturbance, whether from fire, cutting, or drought, can also outcompete native species and dominate landscapes, altering ecosystem dynamics (Nunez-Mir et al. 2019). Given that tree-planting initiatives often aim to enhance biodiversity, ecosystem services, and climate resilience, it is essential to select species that provide these benefits without posing a risk of invasion. Failure to account for these invasion-linked traits can lead to unintended ecological consequences, including biodiversity loss, altered fire regimes, and depletion of water resources (Richardson and Pyšek 2012; Rejmánek and Richardson 2013).

Although native tree species are often favoured in planting schemes due to their ecological benefits, factors such as habitat disturbance can allow certain native trees to expand beyond their natural range, sometimes resulting in negative economic and socio-ecological impacts (Nelufule et al. 2022). For example, the native tree *Dais cotinifolia* can be safely recommended for planting (Table 2), but naturalised populations have been reported (Baard and Kraaij 2014). Large-scale planting of such taxa should be carefully considered.

Regulations and risk analyses

The Risk Analysis for Alien Taxa (RAAT) framework provides a structured, evidence-based approach to assessing the invasion risk of tree taxa before their introduction or widespread planting (Kumschick et al. 2020). It was developed specifically to assist South African decision-makers (and so it aligns with the NEM:BA A&IS Regulations) but the principles are general. This framework can help to identify taxa that pose ecological, economic, or social threats, ensuring that tree-planting initiatives do not inadvertently facilitate biological invasions. By evaluating key factors such as species' invasion history, ecological traits, climatic compatibility, and potential pathways of spread, RAAT helps decision-makers determine whether a tree taxon is low-risk, requires further risk mitigation, or should be restricted entirely. Given the increasing concern over tree invasions and pest-host dynamics, particularly with PSHB, referring to RAAT or other risk analysis frameworks is crucial if planting decisions are to minimise long-term risks.

The NEM:BA A&IS Regulations categorise species based on their invasion risk at a national level; however, in some cases (48 out of 365 terrestrial or freshwater plant taxa listed on continental South Africa) these listings differ by province (although this could be deprecated in future in favour of provincial ordinances, cf. Wilson and Kumschick 2024). A tree species listed as invasive in one region might not be regulated in another, complicating national tree-planting decisions. For instance, certain *Acacia* and *Eucalyptus* species are considered invasive in parts of South Africa but remain widely used in forestry or urban greening elsewhere (Richardson et al. 2023). These regional classifications should be considered to ensure that trees regulated in any part of the country are scrutinised before being included in planting schemes. Additionally, the NEM:BA A&IS Regulations include provision for a list of prohibited taxa, comprising species not yet present in South Africa that may not be imported due to their high invasion risk (a prohibited list was included in the 2014 and 2016, but not the 2020 versions). These regulations underscore the need for a cautious, regionally informed approach when selecting tree species for planting.

Given the variation in species regulations and invasion risks across different regions, the most appropriate spatial scale for applying this protocol is at the provincial or municipal level. Assessments at these finer spatial scales allow for more precise management decisions that align with specific environmental conditions, regulatory frameworks, and socio-economic needs. This localised approach can also foster collaboration between key stakeholders, facilitate integration with urban greening programs, biodiversity conservation plans, and climate resilience strategies tailored to local conditions, and ensure that species assessments account for critical site-specific factors such as climate, soil conditions, and propagule pressure from surrounding landscapes (see Suppl. material 1 for additional site-specific criteria to consider when selecting tree taxa for planting).

To enhance usability by municipal planners and conservation authorities, we emphasise the need to generate spatial products, such as GIS-based risk layers and decision-support maps, that delineate high-risk planting zones based on local species distributions, pest pressure, and environmental conditions. These mapped outputs are critical for site-level guidance and strategic green space planning, especially in data-limited settings.

Pest-pathogen and tree management practices

Effective management of pest-pathogen invasions requires an integrated approach that combines scientific research, biodiversity-based planting strategies, tree health promotion, public awareness, and pest management interventions (Paap et al. 2022).

Sousa-Silva et al. (2023) highlight the need for tree-planting initiatives to move beyond numeric targets and align with long-term forest management objectives. They propose seven principles to enhance success, including integrating initiatives with clear goals, engaging communities, prioritising canopy cover over tree numbers, ensuring post-planting care, monitoring tree losses and gains, promoting species and structural diversity, and addressing inequities in tree distribution. These principles aim to maximise the ecological and social benefits of urban forests. By integrating these strategies, decision-makers can improve the long-term sustainability of urban and natural tree populations while mitigating the ecological and economic impacts of pests/pathogens and tree invasions.

Carnegie and Grant (2025) highlight the critical role of social license in the success of urban biosecurity responses to invasive tree pests. They emphasise that management efforts, such as tree removal or pesticide applications, often face public resistance due to diverse stakeholder values associated with urban trees. The review identifies key actions to improve the social acceptability of control measures, including early stakeholder engagement, trust-building, participatory decision-making, and effective communication about the ecological and economic risks of pest incursions. By proactively addressing social concerns, biosecurity agencies can enhance public support for necessary interventions, ultimately increasing the likelihood of successful pest eradication.

Our decision protocol aligns with these principles by incorporating an evidence-based assessment to promote tree taxa selection by minimising future conflicts between biosecurity actions and urban tree management. By prioritising non-invasive and non-host taxa, the protocol reduces the need for reactive interventions, such as tree removal, that could otherwise trigger public opposition. Moreover, the recommendation to monitor plantings for signs of infestation supports early detection, a key factor in both biosecurity success and stakeholder trust (Liebhold et al. 2012). Integrating social licence considerations into tree selection and biosecurity planning can thus enhance both ecological resilience and public cooperation in managing invasive tree pests like PSHB.

A key consideration in tree selection is prioritising native taxa and promoting diversity to enhance ecosystem resilience and reduce susceptibility to pest-pathogen invasions (Vashist et al. 2025). Monocultures or taxa with similar traits to infested hosts provide little resistance, allowing pest-pathogen populations to persist. A diversity-based planting approach limits host availability, reduces the risk of large-scale pest outbreaks and aligns with broader urban forest resilience principles (Paquette et al. 2021).

Shackleton and Gwedla (2021) explored how colonial and apartheid legacies have shaped urban green infrastructure in South Africa, leading to persistent inequalities in the distribution and composition of urban green spaces. They highlight that wealthier, historically white neighbourhoods retain extensive green spaces dominated by non-native tree species introduced during colonial rule, whereas lower-income areas, historically designated for marginalised communities, have fewer and lower-quality green spaces. This colonial legacy has not only influenced urban ecology but has also resulted in a significant burden of invasive species management. The study also critiques how public green spaces continue to reflect colonial-era aesthetics and recreational norms, often neglecting African cultural perspectives and contemporary urban needs. The authors advocate for a more inclusive, participatory approach to urban greening that considers local identities, worldviews, and ecological resilience. Our protocol allows for the selection of native tree taxa which can support efforts to break from colonial-era planting practices that have contributed to ongoing ecological and social disparities. Prioritising native species and a diversity-based planting approach can support the creation of more ecologically sustainable and socially equitable urban forests. Addressing the historical imbalance in green space distribution, coupled with the proactive selection of appropriate tree taxa, has the potential to foster urban landscapes that are both resilient to biological invasions and more reflective of local cultural and environmental priorities.

The importance of governance for improving the sustainability of tree-planting schemes is receiving increasing attention (Yitbarek et al. 2023). The protocol described here is essential background for both project initiation and planning phases, i.e., guiding the selection of suitable trees.

Monitoring

Establishing a systematic monitoring protocol for trees in regions where pests and pathogens are present or pose a risk of introduction is essential for early detection and effective management (Potgieter et al. 2024). For PSHB, routine visual inspections should be conducted to identify characteristic symptoms of infestation particularly on the trunk and branches, including staining around the entry holes, frass (sawdust-like debris), gumming, and discoloration (van Rooyen et al. 2021). These indicators can signal the presence of PSHB before widespread damage occurs. Incorporating baited traps into monitoring programs can further enhance detection efforts and improve response times. Community science initiatives can facilitate broad-scale surveillance, as local stakeholders can assist in reporting early signs of infestation (Potgieter et al. 2024). Collaboration with environmental and forestry agencies to establish a regional monitoring network would further strengthen detection capabilities and ensure the dissemination of best practices for tree management.

Educating residents, landscape managers, and municipal authorities about the risks of planting pest-susceptible or invasive species and the importance of prompt pest reporting can improve surveillance and rapid response efforts. Where pest-susceptible tree species must be retained for cultural, aesthetic, or ecological reasons, an Integrated Pest Management (IPM) approach can be implemented. This may involve regular monitoring, physical control (e.g., removal of infested material), and, where necessary, the careful application of chemical treatments to high-value trees to limit pest-pathogen spread while minimising unintended ecological consequences.

Applicability beyond Cape Town

The workflow (Fig. 1) and the multi-criterion decision protocol (Fig. 2) can be applied across diverse ecological, geographic, and regulatory contexts. Users can apply the workflow by substituting region-specific datasets, national or municipal planting inventories, and pest-host records relevant to local pest threats. For example, in a Mediterranean-climate city such as Barcelona, Step 3 (Select inclusion criteria) could incorporate drought tolerance alongside tree invasion status. In temperate forest restoration projects in North America, Step 4 (Collate data sources) might prioritise pest-host susceptibility related to Asian Long-horned beetle (*Anoplophora glabripennis*), using United States Department of Agriculture or state-level pest monitoring lists.

Although the protocol was applied to the City of Cape Town as a case study, it can be applied in other regions and planting scenarios. It can accommodate new pest threats, climate-adapted species guidelines, or additional socio-ecological filters. For instance, in urban forestry planning in European cities, the protocol could integrate national invasive species lists alongside provenance risk assessments for climate-resilient species selection. The protocol can also be applied to guide planting initiatives for other regions facing similar plant and pest-pathogen

invasions. For instance, a municipality in southern Europe experiencing threats from pests such as *Xylella fastidiosa* could adapt the protocol by replacing the PSHB-specific host lists with data on *Xylella* host plants, while using European forest and urban tree inventories alongside lists of EU-regulated invasive species. Similarly, climate-adapted species guidelines or provenance risk assessments could be incorporated as additional filtering criteria where relevant. This flexibility ensures that the protocol provides a structured yet adaptable tool for supporting evidence-based tree selection in diverse settings, helping stakeholders align planting initiatives with local ecological, regulatory, and biosecurity priorities.

To further refine suitability for planting, positive selection criteria can be incorporated in the final prioritisation of safe tree candidates. These can include traits associated with climate resilience (e.g. heat and drought tolerance), ecosystem service provision (e.g. canopy cover, carbon storage, pollinator support), and low maintenance requirements. These criteria can be applied to the filtered species pool (those not flagged by any exclusion criteria) to ensure that recommended taxa are not only low risk but also ecologically and functionally valuable. The resulting candidate list can offer a practical resource for municipalities seeking to balance biodiversity, resilience, and risk in tree planting initiatives.

Limitations

Compiling and curating comprehensive species lists can be resource-intensive, particularly in biodiverse, data-poor, or under-resourced regions. In areas with high native and non-native species richness, such as tropical or Mediterranean-climate regions, the initial task of identifying all regionally relevant tree taxa can be time-consuming and dependent on fragmented or inconsistent data sources. While global and national biodiversity databases (e.g., GBIF, GlobalTreeSearch, iNaturalist) provide valuable starting points, these repositories often lack completeness, standardisation, or local verification. Furthermore, in many low- and middle-income countries, institutional capacity for tree monitoring, taxonomic verification, and pest/pathogen surveillance is limited. This can hinder the routine updating and refinement of species lists and reduce the responsiveness of the protocol to emerging threats. Addressing these limitations will require sustained coordination between practitioners, research institutions, herbaria and civil society, as well as investment in open-access data infrastructure, regional taxonomic expertise, and training. The development of collaborative platforms for list curation, anchored in national or municipal environmental planning frameworks, would help improve the feasibility, transparency, and long-term utility of the protocol across diverse contexts.

Richardson and Potgieter's (2024) living tree inventory provides a comprehensive list of tree taxa currently planted in South Africa but does not necessarily account for all tree taxa planted in the country. The inventory also does not account for tree taxa that have not yet been trialled for planting. This presents a knowledge gap that could exclude potentially low-risk, suitable species from decision-making simply due to a lack of widespread testing.

While our list of recommended tree taxa provides a valuable guideline for selecting taxa with a lower likelihood of invasion or PSHB susceptibility, its practical implementation is constrained by the availability of these taxa in commercial nurseries. Many nurseries prioritise species based on market demand, aesthetic appeal, and growth characteristics rather than ecological suitability, which can limit access to

certain recommended species. To bridge this gap, collaboration between researchers, policymakers, and the horticultural industry is essential to encourage the propagation and distribution of these tree taxa. The list can also serve not only as a decision-support tool for planners but also as a priority list for nurseries. By focusing propagation efforts on taxa identified as low-risk, nurseries can help increase the availability of safe species, support diversification of urban and restoration plantings, and reduce the likelihood of inadvertently introducing invasive or pest-prone species. In this way, the list can guide both short-term planting choices and longer-term changes in nursery production practices toward more ecologically sound options.

While this protocol focuses on species-level risk screening, broader considerations such as provenance selection, seed sourcing, and phytosanitary practices are also critical for responsible tree-planting. Economic and logistical barriers, such as limited native tree propagation infrastructure and reliance on imported planting material, can constrain implementation. These factors should be addressed through the integration of complementary frameworks, including provenance risk assessments and climate-adapted species guidelines, within broader urban and forest planning processes.

It is also important to recognise the dynamic nature of PSHB host susceptibility and the ongoing evolution of suitable host lists. As PSHB is a relatively recent invader in regions like South Africa and Australia, not all tree taxa within these invaded ranges have had equal exposure to the beetle and the fungus *N. euwallaceae*, suggesting a "host debt". The current living tree inventory in South Africa and existing host lists are based on infestations observed since the beetle's arrival. Consequently, tree taxa that are not yet widely planted or that occur in areas not yet significantly invaded might not have been adequately evaluated. As PSHB continues to spread, it is likely to encounter and colonise new tree taxa, leading to further expansion of the known host range. Our present understanding of PSHB hosts thus represents a temporal snapshot; this will change as the invasion unfolds.

Additional information

Conflict of interest

JW was part of the editorial team for the special issue 'Developing lists of alien taxa in the Global South: workflows, protocols, processes, and experiences', but took no part in the peer review and decision-making process for this paper.

Ethical statement

No ethical statement was reported.

Use of AI

No use of AI was reported.

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Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by LJP. The first draft of the manuscript was written by LJP, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability

The final filtered dataset generated and analysed during the study has been archived on Zenodo: https://doi.org/10.5281/zenodo.15259591 (Potgieter 2025).

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Supplementary material 1

Additional site-specific criteria to consider when selecting tree taxa for planting

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